GEORGIA INSTITUTE OF TECHNOLOGY

OFFICE OF CONTRACT ADMINISTRATION

SPONSORED PROJECT INITIATION

Date: 8/8/78

Project Title: Multiple Frequency Antenna Study

Project No: A-2172

Project Director: J. Wang

Sponsor: U.S. Air Force; AFSC Aeronautical Systems Division

Agreement Period: From 6/26/78 Until 9/26/79

Type Agreement: Contract No. F33615-78-C-1529

Amount: $123,909 (Partially funded at $40,000 thru 9/30/78).

Reports Required: Program Schedule; Monthly R&D Status Reports; Monthly Perf. & Cost Reports; TRACE; Abstract of New Technology; Presentation Material; Minutes; Conferences; Final Technical Report.

Sponsor Contact Person (s):

Technical Matters

Mr. William C. Adams
AFAL/RWM
Avionics Laboratory
Wright Patterson AFB, OH 45433

Contractual Matters
(thru OCA)

ONRRR
CAMPUS

Defense Priority Rating: None

Assigned to: Systems and Techniques Laboratory (School/Laboratory)

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SR10404

GEORGIA INSTITUTE OF TECHNOLOGY
OFFICE OF CONTRACT ADMINISTRATION

SPONSORED PROJECT TERMINATION

Date: 1/8/79

Project Title: Multiple Frequency Antenna Study

Project No: A-2172

Project Director: J. Wang

Sponsor: US Air Force; AFSC Aeronautical Systems Division

Effective Termination Date: 11/28/78

Clearance of Accounting Charges: 12/31/78

Grant/Contract Closeout Actions Remaining:

- X Final Invoice and Closing Documents
- _ Final Fiscal Report
- X Final Report of Inventions
- X Govt. Property Inventory & Related Certificate
- X Classified Material Certificate
- _ Other ______________

Assigned to: Systems & Techniques (School/Laboratory)

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CA-4 (3/76)

A-2172

ENGINEERING EXPERIMENT STATION

GEORGIA INSTITUTE OF TECHNOLOGY • ATLANTA, GEORGIA 30332

17 October 1978

United States Air Force
Air Force Avionics Laboratory
Wright-Patterson AFB, Ohio 45433

Attention: Mr. W. C. Adams/RWM

Subject: Program Review Minutes

Reference: Contract No. F33615-78-C-1529, Multiple Frequency Antenna Study (MUFANS)

Gentlemen:

Attached are the Minutes of the Program Review of the referenced contract held at Georgia Tech on 5 October 1978. The Minutes are organized in a simplified summary form based on the handwritten records taken by the Georgia Tech participants in the review.

Respectfully submitted,

Johnson J. Wang
Project Director

/jm

MULTIPLE FREQUENCY ANTENNA STUDY (MUFANS)
(Contract No. F33615-78-C-1529)

MINUTES OF PROGRAM REVIEW

The MUFANS program review was held on 5 October 1978 at the Baker Building conference room of Georgia Institute of Technology. The following persons were in attendance.

W.C. Adams	AFAL/RWM
J.M. Prevish	AFAL/RWM
A.E. Blume	AFAL/DHM
J.J.H. Wang	Georgia Tech
F.L. Cain	Georgia Tech
V.K. Tripp	Georgia Tech
J. Glish	CDC
R.W. Peterson	CDC

OPENING REMARKS (W.C. Adams)

Mr. Adams emphasized that the Air Force has given Georgia Tech a very challenging antenna design problem. It was pointed out that the primary emphasis of this program should be on the tradeoff study. He stated that the purpose of the point design is merely to demonstrate the design feasibility, and therefore, specific performance requirements are not critical at this time. The ultimate goal is to obtain adequate tradeoff data so that some "give and take" considerations in the design can be assessed.

PRESENTATIONS (J.J. Wang and V.K. Tripp)

An executive summary of the program and the recommendation of an antenna approach were presented in viewgraphs by J.J. Wang and V.K. Tripp of Georgia Tech. Copies of the viewgraphs used in this 2-1/2 hour presentation were distributed to all participants in the meeting, and extra copies were also given to W.C. Adams for further distribution at AFAL. The presentation began with an executive summary which included a discussion of the purpose of this review, the task breakdown, the schedule, and technical difficulties. The recommended design approach is a system of separate forward-looking and side-looking antennas. An array of slots or dipoles would perform the side-looking function and a transmission-line antenna or unbalanced V-dipole would be forward-looking.

After the executive summary, a review of requirements and design goals for the antenna was presented with emphasis on those having technical difficulties.

The process by which the candidate antennas had been evaluated was then described, and data supporting this selection were presented. Analytical data generated for the recommended design approach were then discussed in detail. Design difficulties such as the high elevation beam peak and high-power handling capability were pointed out and discussed.

DISCUSSIONS AND COMMENTS

1. W.C. Adams pointed out that the forward-looking mission might not require as much power as the side-looking one and that the present power requirements included some allowance for mismatches and losses.

2. W.C. Adams indicated the need to look at the possible application to U-2 aircraft. Georgia Tech agreed to include it in the tradeoff study.

3. The question of cross-polarization and frequency bandwidth was raised regarding CDC's I, C, and O slots. On the other hand, the possible advantage of slot's better impedance characteristics and suitability to the pod geometry was also recognized. It was also mentioned by Wang that the slot was more difficult to deal with either analytically or experimentally.

4. Blume asked about the effects of neglecting the mutal coupling between slots in Georgia Tech's slot array analysis. Tripp cited earlier similar work at Ohio State, admitting that sometimes, especially when scanning the array away from broadside, mutual coupling might not be negligible.

5. Blume asked about the details of Georgia Tech's approach on power handling capability. Wang explained that the power handling capability would be assessed analytically on the basis of the feasibility of electrical components involved. Glish suggested that the solid-state array employing a number of separate transmitters might be worth consideration for achieving high power. Adams indicated that Georgia Tech should examine this separate transmitter approach.

6. Blume asked whether the forward-looking and side-looking antennas are separate systems using separate pods. Adams answered that the forward-looking system and side-looking system are separate systems to be mounted on separate instrument pods, but it would be nice to integrate them into a single pod. Both Blume and Wang then commented that this certainly would simplify the design problem since the mutual coupling and interference between the forward-looking and side-looking antennas would not exist.

7. Glish indicated that mirror image lobe suppression was required over a wide angle to allow for the crab angle of the aircraft. Wang pointed out that this would add significantly to the design difficulties.

8. Adams emphasized the desire to consider all the frequencies between F_1 and F_3. Wang pointed out the resonance problem at F_1 but indicated that frequencies at 1.1 F_1 and up to F_3 would be considered.

9. Blume asked whether high radiation at large depression angles could cause any problem. Adams answered that it would not cause any problem other than wasting power.

10. Wang asked what allowable space in the pod can be used to place the antennas, such as slots and their feed network. Adams indicated that perhaps as much as 20 percent of the pod volume could be allocated for the antenna.

11. Adams said that the recommended antenna approach was somewhat vague. Wang pointed out that the vagueness, centered at the question of using slot or dipole, was partially due to our waiting for slot data from CDC.

12. Tripp indicated the need to get I slot data from CDC as soon as possible so that he could assess its cross-polarization problem when mounted under the aircraft.

CONCLUDING REMARKS AND ACTIONS ITEMS (W.C. Adams)

1. CDC should provide performance data for I slots to Georgia Tech, with a copy to Adams. Georgia Tech should provide data on circumferential slots. A decision to select between slot and dipole antennas should be made before 1 November.

2. Georgia Tech should conceive data configurations such as curves and tables for use in the cost performance tradeoff study. These should be communicated to Adams in either formal or informal formats in the near future.

A-2172

ENGINEERING EXPERIMENT STATION
GEORGIA INSTITUTE OF TECHNOLOGY • ATLANTA, GEORGIA 30332

7 August 1978

Air Force Avionics Laboratory
Air Force Systems Command
United States Air Force
Wright-Patterson Air Force Base
Ohio 45433

Attention: Mr. C. Adams, RWM

Reference: Contract No. F33615-78-C-1529

Title: "Multiple Frequency Antenna Study (MUFANS)"

Subject: Monthly Status Report No. 1

Gentlemen:

A summary of the progress on the referenced contract for the period 26 June through 26 July is contained herein. The effective starting date was specified as 26 June 1978 during the contract negotiation. The program has been designated by Georgia Tech as Engineering Experiment Station Project A-2172. The project is under the general supervision of Mr. F. L. Cain, Chief of the Electromagnetic Effectiveness Division, and under the direct supervision of Dr. J.J. Wang, Project Director. Activities this month included (1) a kick-off meeting at Wright-Patterson AFB, (2) program scheduling and planning, and (3) identification of preliminary conceptual designs and tradeoff studies.

The program kick-off meeting was held on 21 July 1978 at AFAL and was attended by Captain M. Poore, Messers C. Adams, A. Blume, J. Pasek, and H. Lapp of AFAL, by Dr. R. Peterson, Messers. J. Bigham, Jr., and S. Moulton of CDC, and by Drs. J. Wang and C. Ryan, Jr. of Georgia Tech. During the meeting, the program objectives and technical requirements were discussed. A program schedule as shown in Figure 1 was presented and accepted in the meeting. During the meeting, major technical difficulties which must be addressed were identified as the high power-handling requirement and pattern beam-shaping to achieve a high gain near the horizontal plane. CDC presented experimental results for slot antenna configurations on a cylinder. These slot antennas will be considered by Georgia Tech for potential application to MUFANS.

Candidate antennas being considered in the design study include the following types:

1. TEM-line antenna,
2. Multi-turn loop,
3. Cavity-backed slot,
4. Dipole,
5. Transmission-line antenna
6. Microstrip antenna, and
7. Towel-bar antenna.

During the next month, first-order analyses will be conducted to assess the technical difficulties associated with requirements of high-power handling and beam-shaping near horizontal plane. A first-order theoretical design study will also be performed to arrive at an optimized antenna configuration.

Sincerely,

Johnson J. Wang
Project Director

Approved:

Fred L. Cain
Chief,
EM Effectiveness Division

Project A2172 (MUFANS) Schedule

1. Conceptual designs
   a. Identification of feasible antennas and conceptual antenna/aircraft designs
   b. Trade-off study of preliminary selection of antennas
   c. Program review and final selection of antenna

2. Development of computer programs
   a. Antenna/pod configuration
   b. Antenna/pod/aircraft configuration

3. Antenna system design and fabrication
   a. Antenna
   b. Feed network
   c. Pattern and frequency switches

4. Scale-model tests
   a. Copper-plating or gold-leafing of aircraft model
   b. Antenna/aircraft measurements

5. Performance trade-offs of varying system parameters

6. Evaluation of impedance and radiation efficiency

7. Final Report
   a. Final report draft
   b. Final report

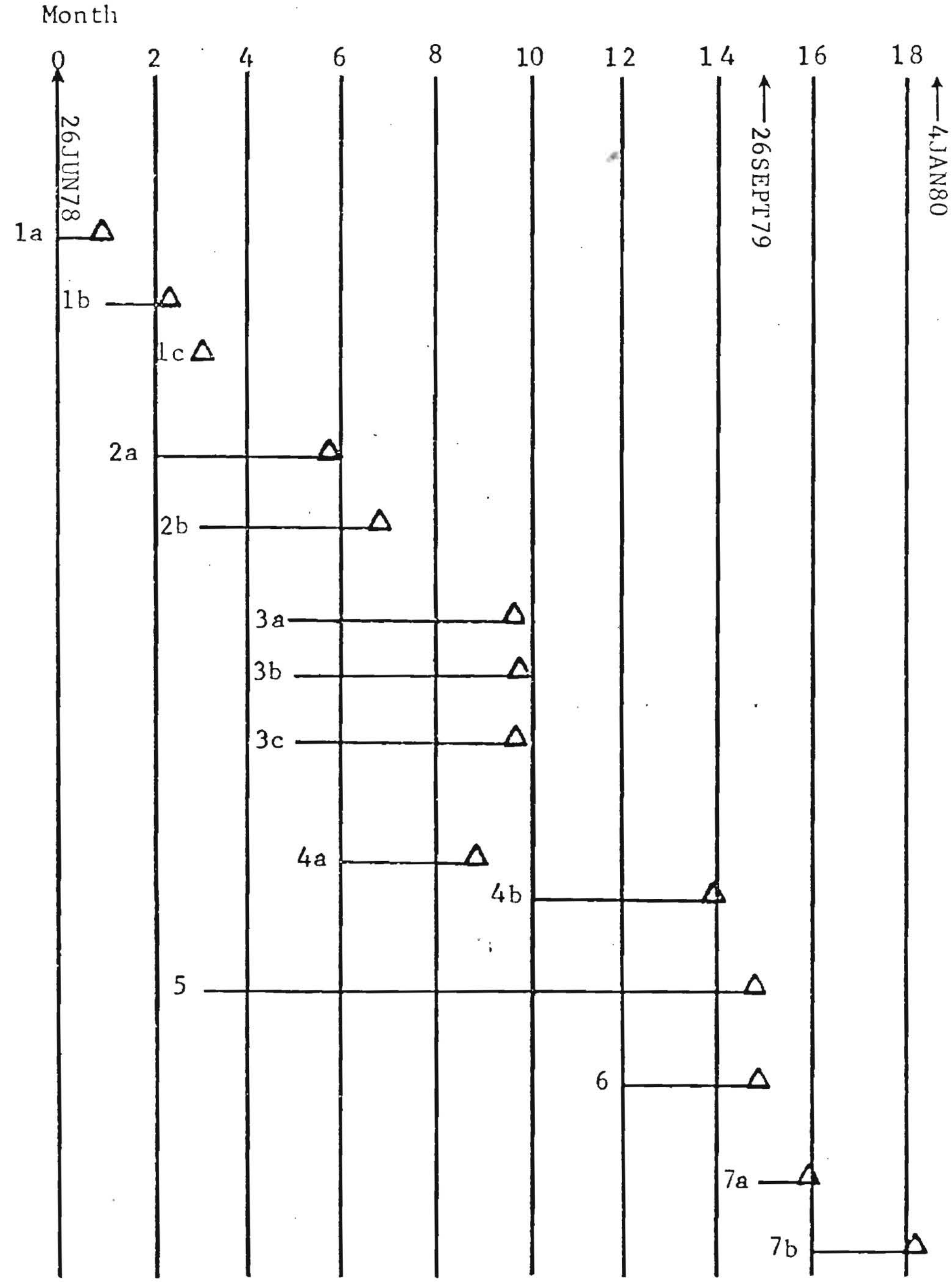


Figure 1. Program schedule

A-2172

ENGINEERING EXPERIMENT STATION

GEORGIA INSTITUTE OF TECHNOLOGY • ATLANTA, GEORGIA 30332

30 August 1978

Air Force Avionics Laboratory
Air Force Systems Command
United States Air Force
Wright-Patterson Air Force Base
Ohio 45433

Attention: Mr. W. C. Adams, RWM

Reference: Contract No. F33615-78-C-1529

Title: "Multiple Frequency Antenna Study (MUFANS)"

Subject: Monthly Status Report No. 2

Gentlemen:

A summary of the progress on the referenced contract for the period 26 July through 26 August 1978 is contained herein. Activities this month included (1) a first-order analysis of the effect of aircraft wings on antenna patterns and (2) an analysis of a slot antenna on an infinite circular cylinder.

As pointed out in the kickoff meeting at AFAL on 21 July 1978 and Monthly Status Report No. 1, the aircraft wings are expected to have a predominant effect on the antenna pattern. The wings tend to suppress the antenna pattern downward, which makes it difficult to achieve a beam peak at an angle near horizontal. The effect of the wings decreases with the increasing directivity of the antenna. As shown in Figures 1 and 2, the present design goal of pointing the beam peak at an angle between -5° and -10° below horizontal requires an antenna having a directivity of 12 dB or more. On the other hand, the maximum directivity achievable for a practical antenna is inherently limited by its physical size in terms of the operating wavelength. It is extremely difficult to achieve a directivity of 12 dB for the present design frequencies. As a result, the present elevation pattern requirements and antenna mounting locations must be further examined. Analytical data needed for this consideration are being generated but will not be presented via monthly reports due to their classification.

Analysis of pod-mounted slots has been performed by approximating the instrument pod with an inifinite circular cylinder. For elevation patterns about the axis of the pod, the infinite cylinder is considered to be a good approximation. Figure 3 shows that the computer program was validated by comparing the calculated and measured patterns. Figures 4 and 5 show the elevation patterns for a circumferential slot at two frequencies. The directivity is only several dB, much lower than the 12 dB required. To enhance the antenna directivity, an array, for

Monthly Status Report No. 2
Contract No. F33615-78-C-1529
30 August 1978

which slots can be used as array elements, is being employed. It is expected that at least several more dB improvement in directivity can be achieved by this array technique.

During the next month, the conceptual design study will be completed and an optimized antenna approach will be selected and recommended for detailed analysis, design, and breadboard fabrication and testing. In addition, the development of a computer program for an extensive design and tradeoff study will be initiated.

Respectfully submitted,

Johnson J. Wang
Project Director

Approved:

Fred L. Cain
Chief,
EM Effectiveness Division

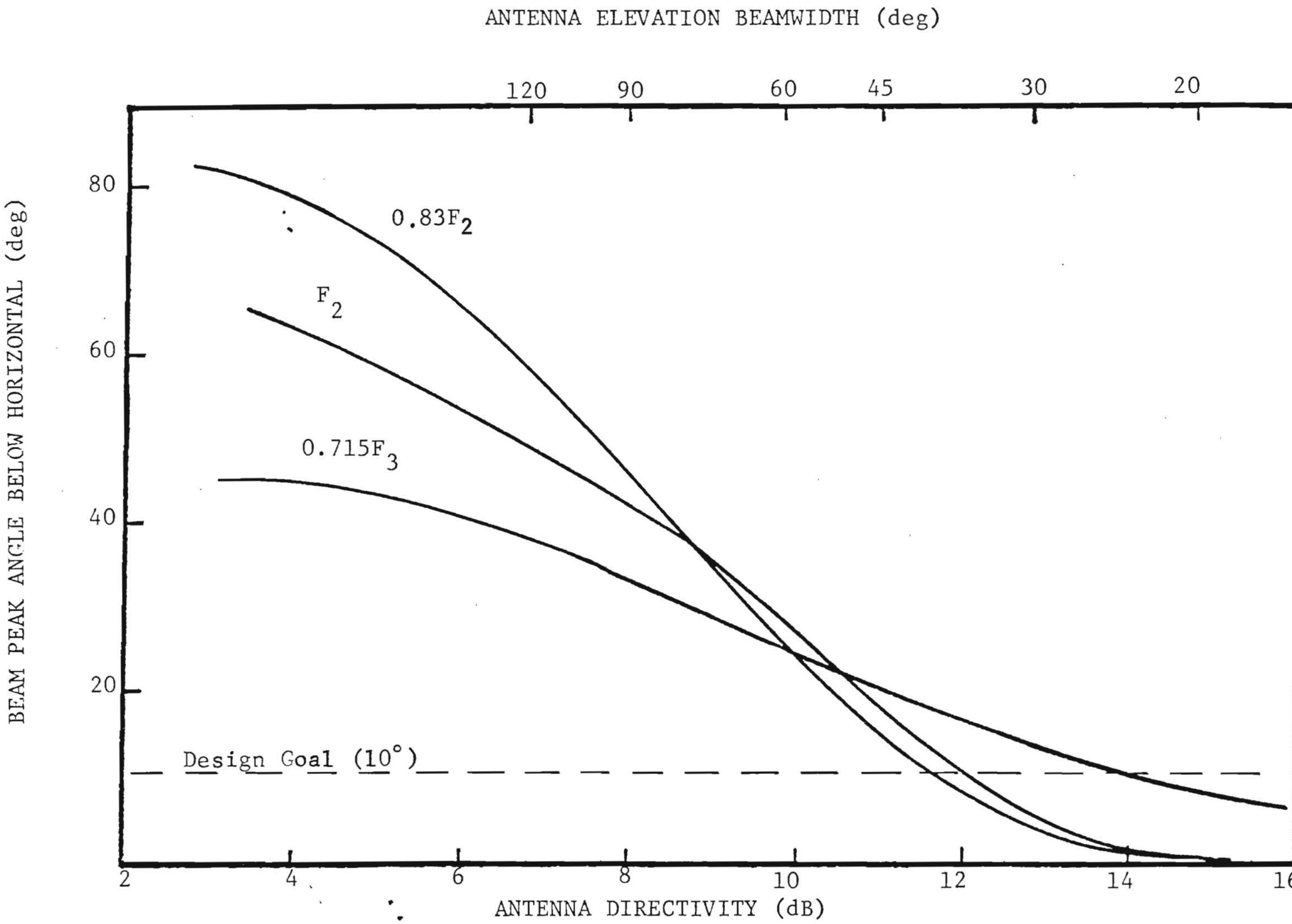


Figure 1. Beam peak position as a function of directivity of an antenna located four feet below the aircraft belly at various frequencies F.

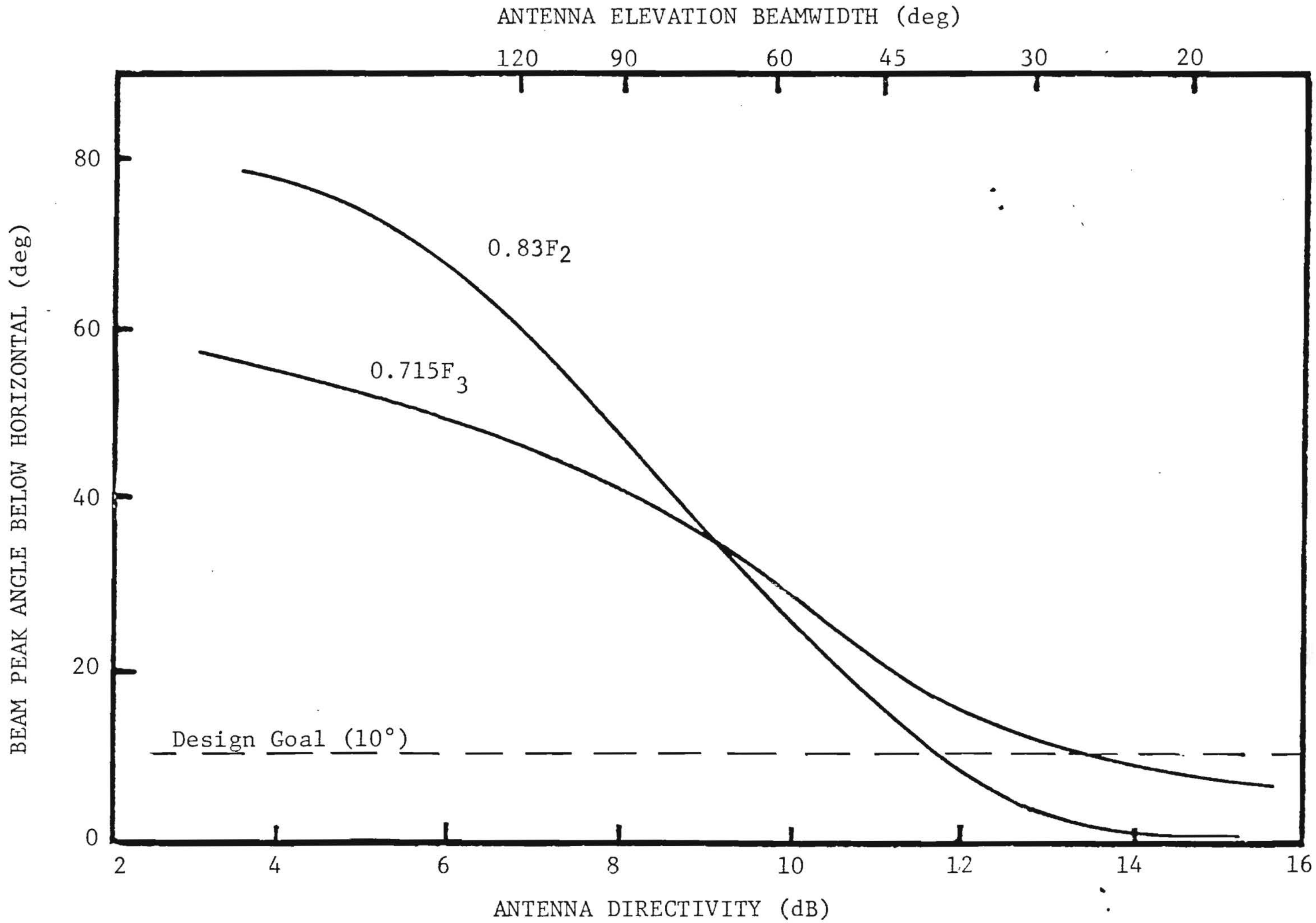


Figure 2. Beam peak position as a function of directivity of an antenna located three feet below the aircraft belly at various frequencies F.

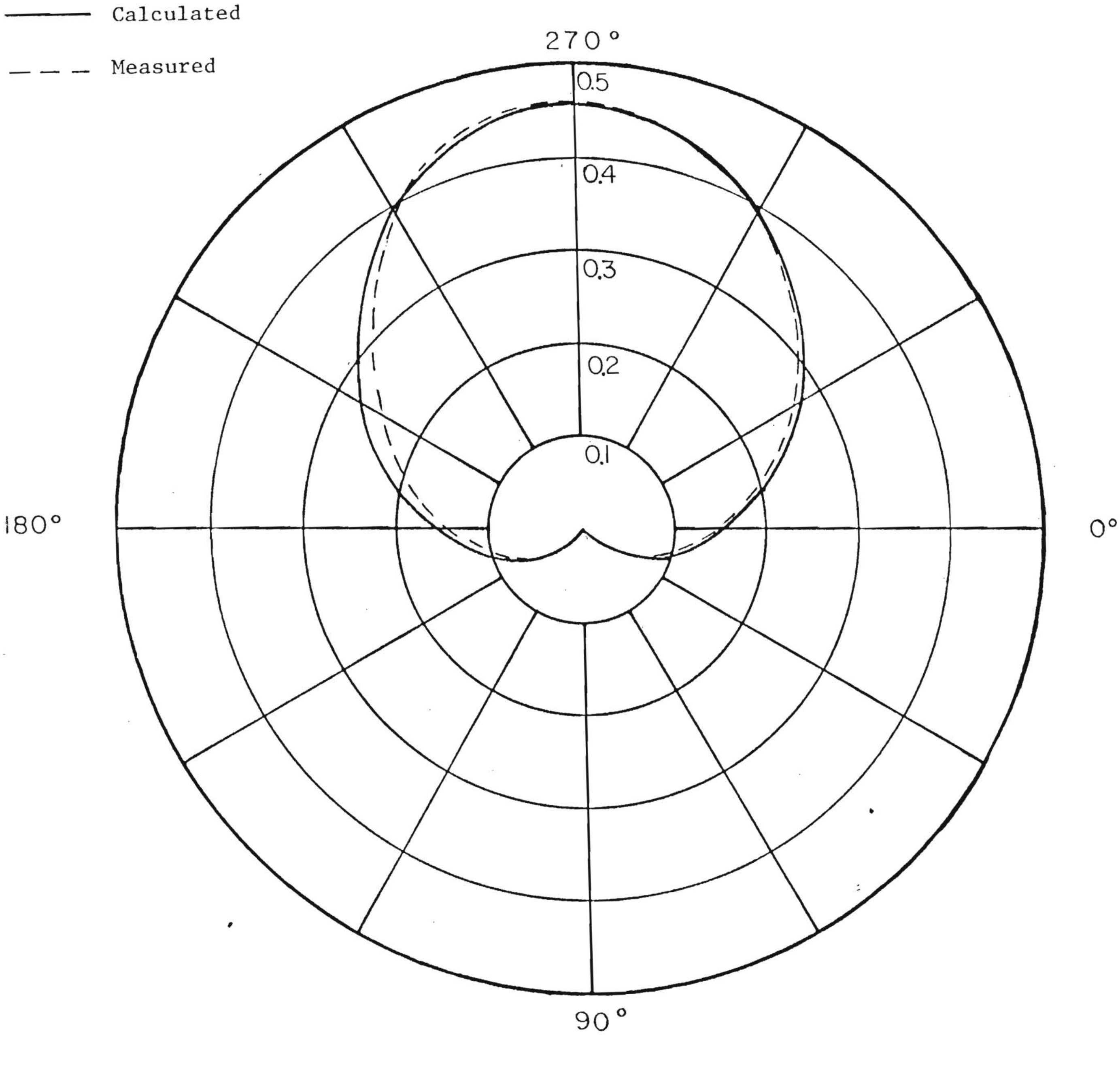


Figure 3. Verification of analysis of a circumferential slot on a cylinder.

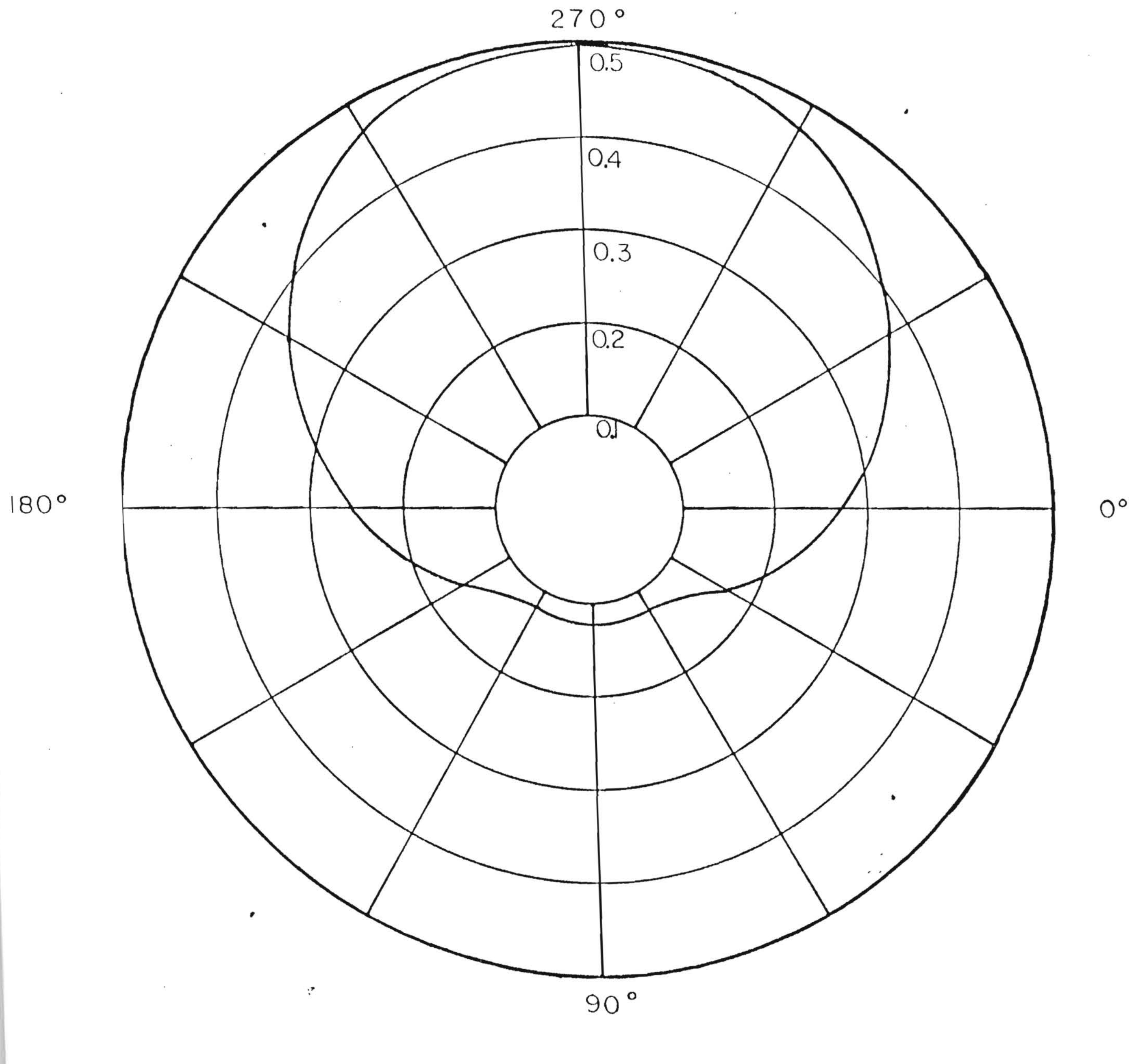


Figure 4. Roll pattern for a circumferential slot on a cylinder at frequency F_2.

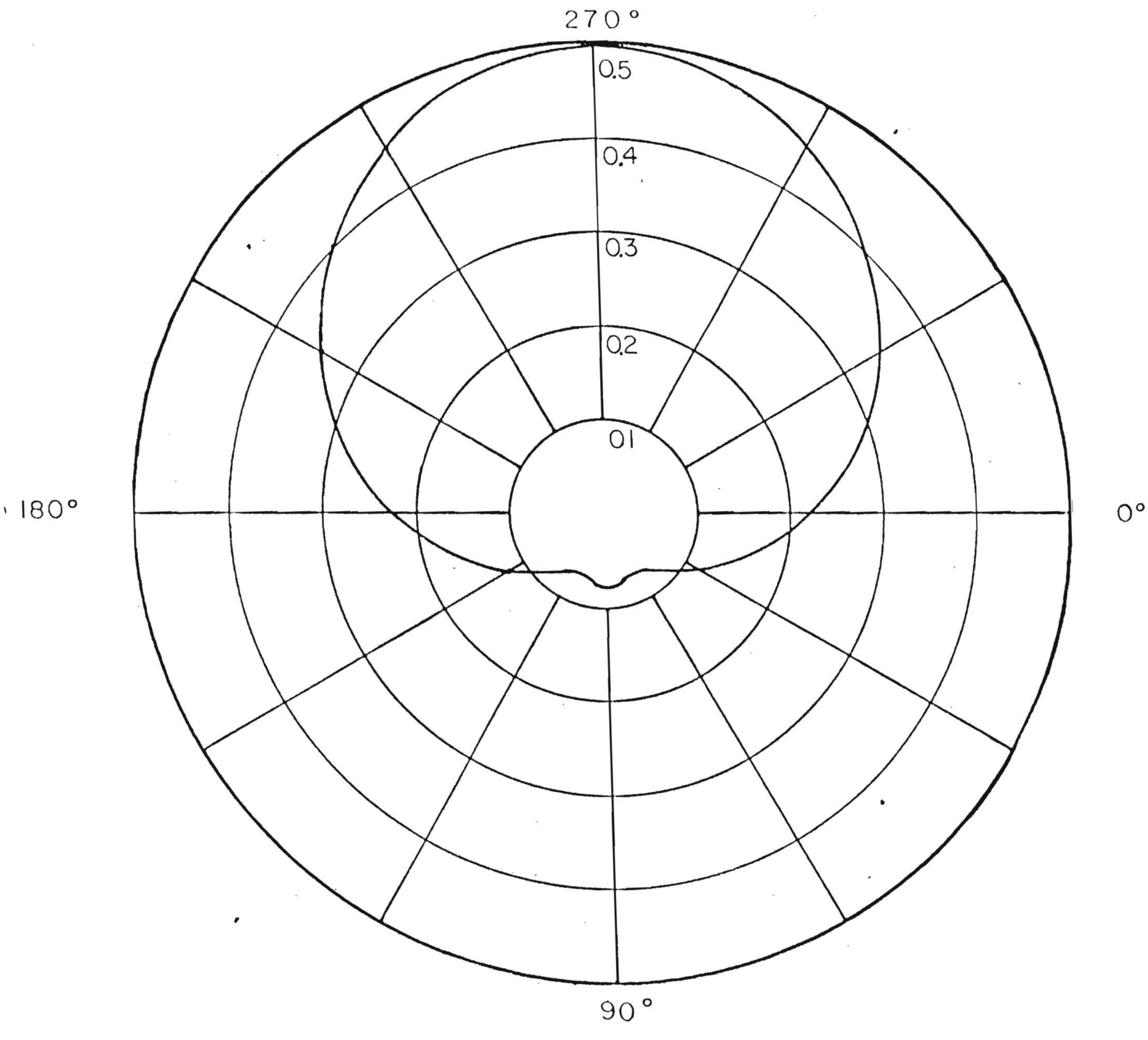


Figure 5. Roll pattern of a circumferential slot on a cylinder at frequency 0.715 F_3.

A 2172

ENGINEERING EXPERIMENT STATION

GEORGIA INSTITUTE OF TECHNOLOGY • ATLANTA, GEORGIA 30332

26 September 1978

Air Force Avionics Laboratory
Air Force Systems Command
United States Air Force
Wright-Patterson Air Force Base,
Ohio 45433

Attention: Mr. W. C. Adams, RWM

Reference: Contract No. F33615-78-C-1529

Title: "Multiple Frequency Antenna Study (MUFANS)"

Subject: Monthly Status Report No. 3

Gentlemen:

A summary of the progress on the referenced contract for the period 26 August through 26 September is contained herein. Activities this month included (1) a visit of the Monitoring Project Engineer, Mr. W. C. Adams, to Georgia Tech for technical discussions, (2) selection of a conceptual design approach to be recommended for further study, and (3) initiation of development of a computer program for analyzing slot antennas on a body of revolution such as an instrument pod.

Mr. Adams visited Georgia Tech on 18 September 1978 to review both the technical and management aspects of the program. He also presented guidelines on how the program review, tentativley scheduled to be on 5 October 1978, should be conducted. After a close examination of the various potential antenna approaches presented in the kickoff meeting, a conceptual design approach consisting of separate forward-looking and side-looking antennas has been finalized. This selected antenna approach will be presented in detail in the forthcoming program review for approval by the Air Force.

Two forward-looking antennas, as conceptually depicted in Figure 1, are recommended for final consideration. These antennas which consist of an unbalanced V dipole and a terminated transmission-line antenna are conformally structured near the front of the instrument pod with a protrusion of about 3 inches. The final selection between these two design configurations will depend on the outcome of further detailed analysis of their pattern characteristics and power-handling capability.

The recommended side-looking antenna is an array of two or four elements, which are either horizontal dipoles or circumferential slots. The C, I, and O slot configurations conceived at CDC can be considered as variations of the generalized slot approach; these configurations are more suitable for impedance matching but may have a high cross-polarization component and a narrow bandwidth. Whether the C, I, and O versions of slots will be employed in the side-looking array will be determined later when comprehensive data for them become available and are thoroughly compared with the merits of other array elements.

The side-looking antenna will consist of a circular ring array on the surface of the pod. A major effort during this reporting period was to develop a computer algorithm for calculating the radiation pattern of an array of slots on the surface of an infinitely long circular cylinder. This computer program has been coded, debugged, and used in optimizing a two-slot array for maximum directivity in the desired direction. Figures 2 and 3 show the elevation patterns of a two-slot array with different excitation schemes. Since an infinitely long cylinder is not an exact representation of an instrument pod, the development of a computer program for a general body of revolution (for which the pod is a special case) has been initiated, as originally planned. The analysis necessary for the computer coding is near completion, and most of the technical difficulties, such as the integration of impedance matrices, have been overcome. After an optimized array configuration is obtained, it will be incorporated into a GTD (Geometrical Theory of Diffraction) algorithm to calculate the overall pattern, including the effects of the aircraft wing structure.

Activities during the next monthly reporting period will include (1) analysis and coding for the radiation problem involving a general body of revolution such as a pod, (2) modification of the GTD algorithm to handle antennas with arbitrary radiation characteristics, (3) program review to select an antenna approach for detailed study, and (4) detailed design study of the selected antenna configuration.

Respectfully submitted,

Johnson J. Wang
Project Director

Approved:

Fred L. Cain
Chief,
EM Effectiveness Division

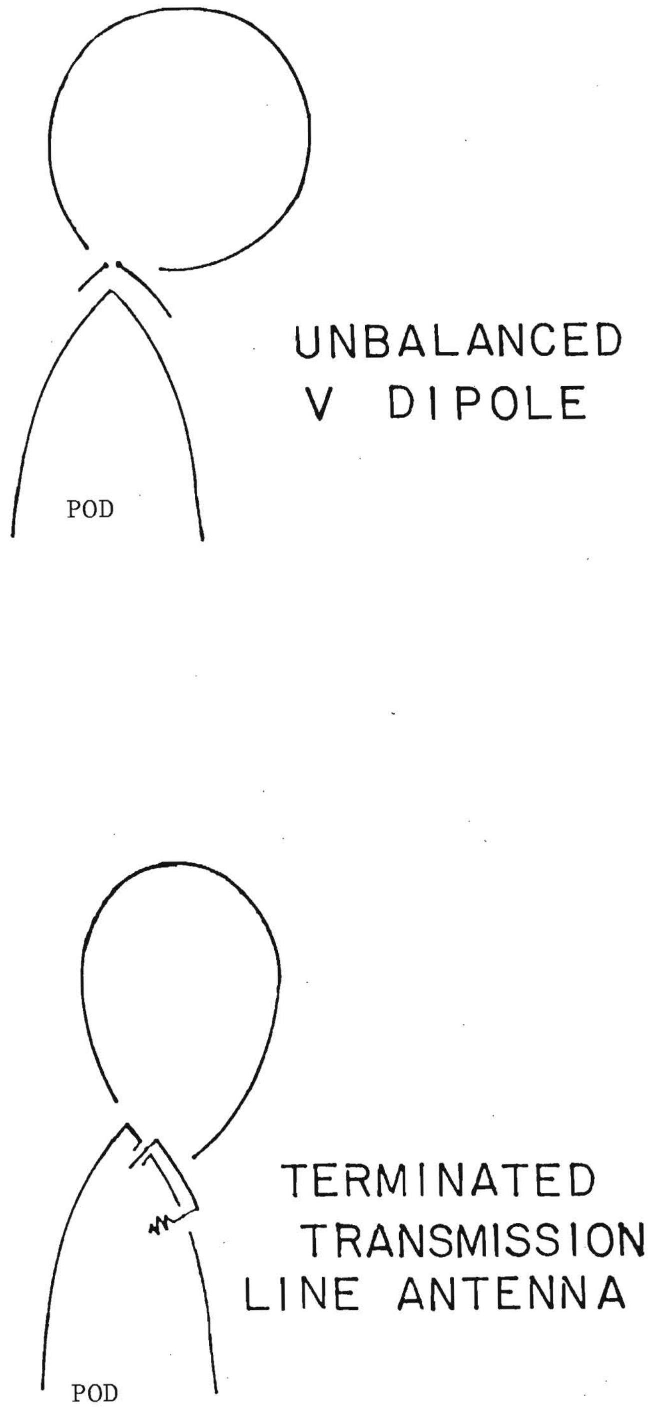


Figure 1. Design approach for foward-looking antennas.

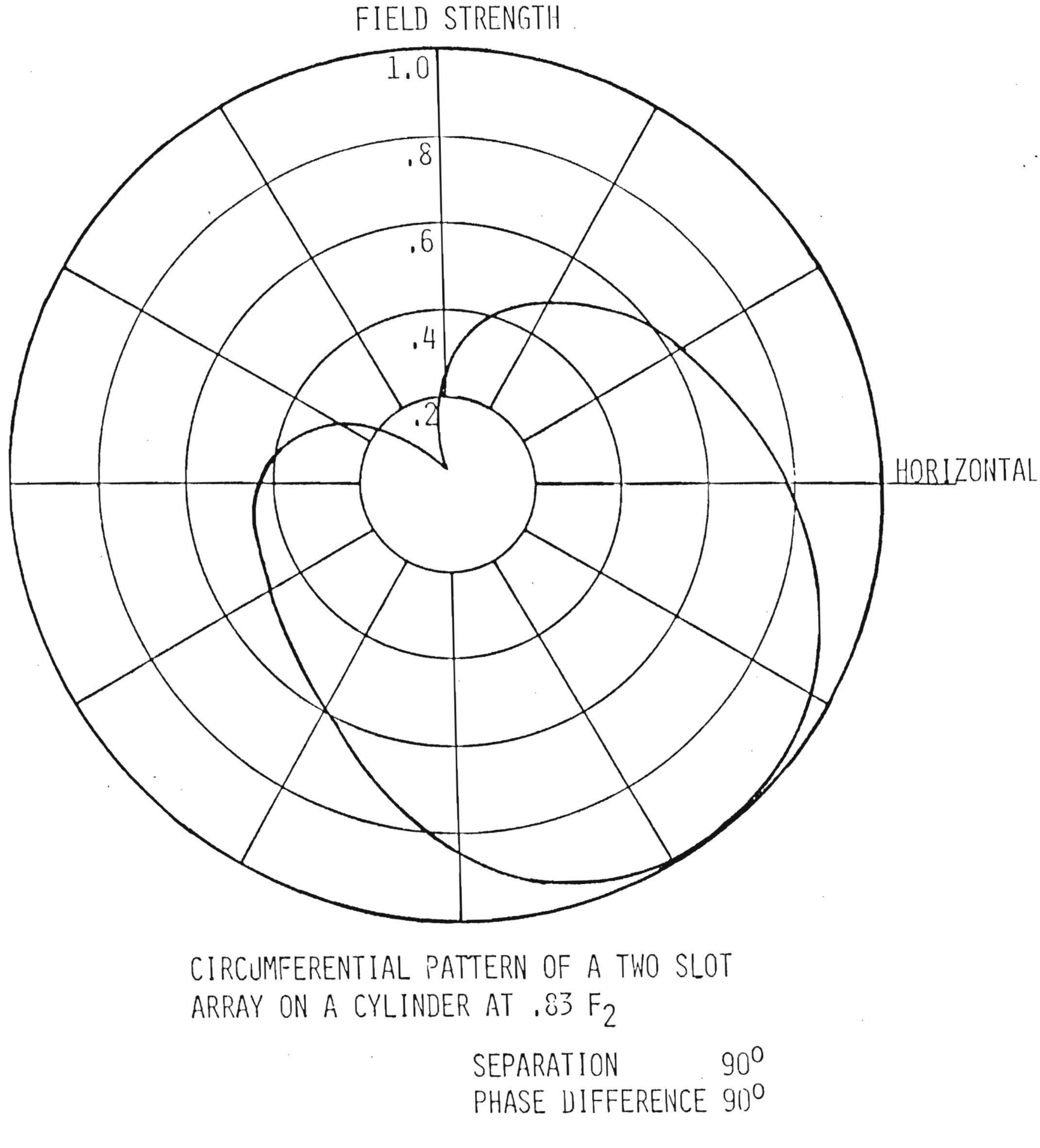


Figure 2. Elevation pattern of a two-slot array on instrument pod in the absence of the aircraft (separation = 90°).

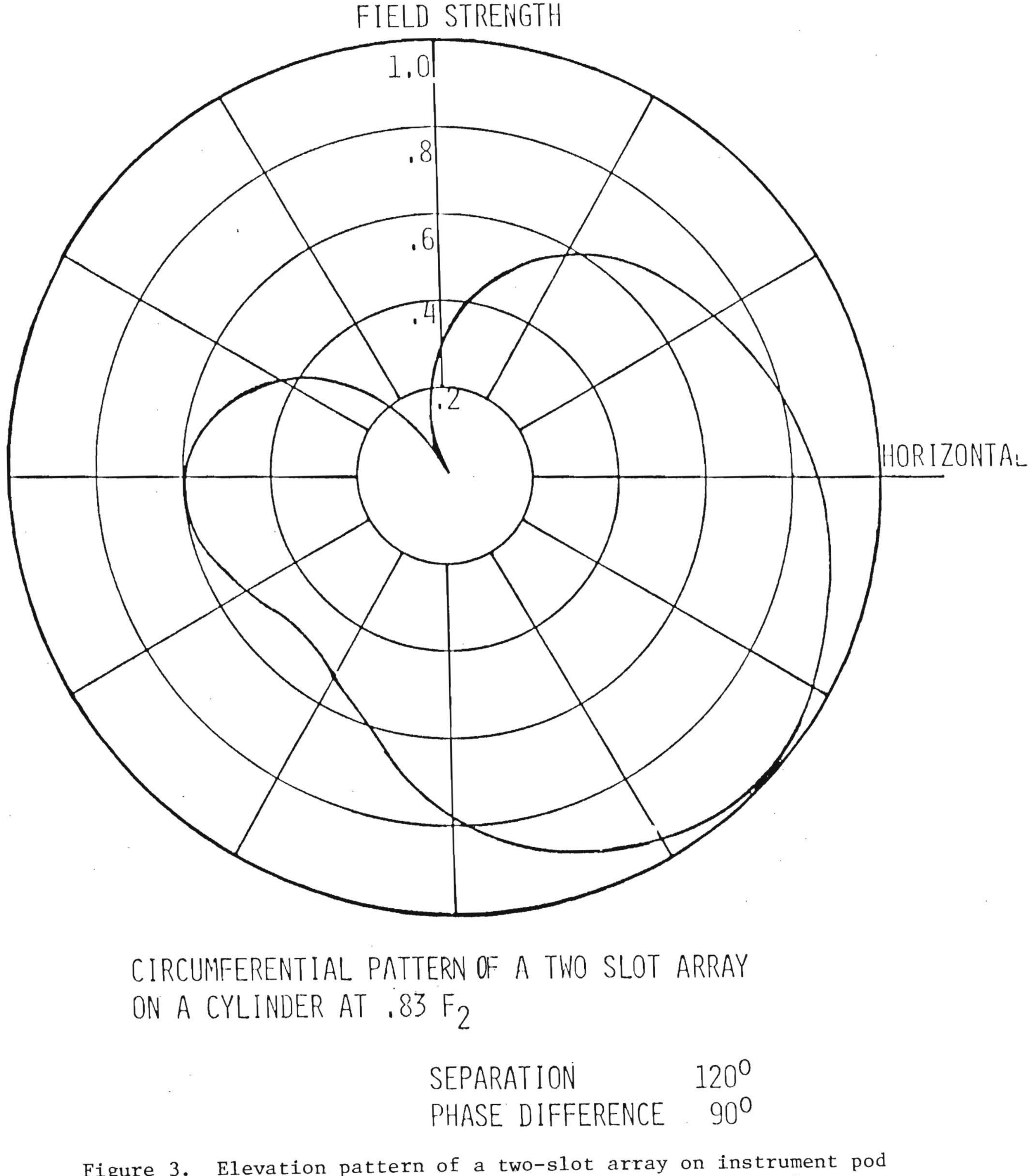


Figure 3. Elevation pattern of a two-slot array on instrument pod in the absence of the aircaft (separation = 120°).

A-2172

ENGINEERING EXPERIMENT STATION
GEORGIA INSTITUTE OF TECHNOLOGY • ATLANTA, GEORGIA 30332

27 October 1978

Air Force Avionics Laboratory
Air Force Systems Command
United States Air Force
Wright-Patterson Air Force Base
Ohio 45433

Attention: Mr. W. C. Adams, RWM

Reference: Contract No. F33615-78-C-1529

Title: "Multiple Frequency Antenna Study (MUFANS)"

Subject: Monthly Status Report No. 4

Gentlemen:

A summary of the progress on the referenced contract for the period 26 September through 26 October 1978 is contained herein. Activities this month included (1) the program review, (2) the selection of a specific antenna approach for the point design, (3) compilation of a list of planned tradeoff studies, and (4) computer program development.

The program review, attended by AFAL, CDC, and Georgia Tech personnel, was held at Georgia Tech on 5 October 1978 for the review of various system concepts and design data and the recommendation of a specific approach for the point design. Copies of the presentation materials were distributed at the review. The minutes of the review were later prepared and distributed by Georgia Tech. The highlights of the review were (1) Georgia Tech's recommendation of an antenna approach consisting of separate forward-looking and side-looking antennas, (2) the techincal monitor's emphasis on tradeoff studies and his request for a list of tradeoff studies to be derived and (3) the decision to make a final selection between slot and dipole antennas in the recommended point design before 1 November 1978.

Georgia Tech recommended an antenna system consisting of separate forward-looking and side-looking antennas. During the subsequent discussion period, it was clarified by the Technical Monitor, Mr. Adams, that the basic system concept as envisioned by him contained separate forward-looking and side-looking systems mounted on separate instrument pods. However, he indicated that it would be desirable to integrate these two systems into a single pod.

The recommended forward-looking antenna consisted of a transmission line antenna or an unbalanced V dipole. The recommended side-looking antenna is an array of slot or dipole elements. The rationale, methodology, and supporting data by which the antenna was selected were presented and accepted in the meeting. However, the technical monitor indicated that a decision to choose between the slot and the dipole in the side-looking array should be made before 1 November 1978, and that CDC should provide I-slot data to support Georgia Tech's antenna selection.

Within ten days after the review, Georgia Tech received I, C, and O slot data from CDC. Based on the available data, Georgia Tech selected the dipole antenna over the slot antenna as the element of the side-looking array. It should be understood that the merits of the recommended design approach are in the array concept -- not so much in whether a dipole or a slot is chosen as the array element. The preference of the dipole to the slot arises from the following considerations: (1) electrical performances of the dipole antenna on a pod are slightly superior to those of the slot, (2) experiments are easier in practice to perform on dipoles than on slots, and (3) existing computer programs at Georgia Tech handle dipoles more accurately than slots. These technical considerations are discussed in detail in the following paragraphs.

The I-slot was eliminated from further consideration after CDC's data had been received and examined. The available data from CDC, which consisted of a pattern equation and some measured impedance and azimuthal pattern data, did not include information on the elevation pattern characteristics and were primarily for the forward-looking application. Study at Georgia Tech also indicated that the I, C, and O slots had high cross-polarization and narrower pattern and impedance bandwidths. CDC confirmed the cross-polarization but indicated that it would be less than 15 percent. CDC's data also showed that I, C, and O slots had a broadside dip in their azimuthal patterns, and as a result, could not be used in the side-looking array.

The straight circumferential slot, which did not have the cross-polarization and pattern bandwidth problems found in the I, C, and O slots, was also eliminated. The selection of the dipole in preference to the straight slot resulted from the following considerations.

The impedance bandwidth of an isolated dipole is equivalent to that of a slot on an infinite ground plane radiating on both sides of the plane because they are complementary antennas. When the dipole is located near an instrument pod, its impedance bandwidth becomes narrower. Similarly, the slot, being terminated in a cavity inside the pod instead of radiating on both sides of the ground plane, has a narrowed bandwidth. The bandwidth of an antenna can be estimated on a first-order basis from its quality factor, Q. Since the computation of Q for an antenna on pod is extremely difficult, comparison of Q is made for the case of an infinite ground plane -- the limiting case asthe pod diameter is made large. For a cavity-backed slot on an infinite ground plane, its quality factor is

$$Q_{slot} = \frac{3}{4\pi^2} \frac{\lambda^3}{V}, \tag{1}$$

where λ = the operating wavelength, and
V = the volume of the cavity.

For the comparable case of a dipole parallel and spaced at distance S from an infinite ground plane, its quality factor is

$$Q_{dipole} = \frac{\omega}{2R} \frac{dX}{d\omega} \Bigg|_{\text{resonance}} \Bigg|_{\text{spacing} = s}, \tag{2}$$

where ω = the operating radian frequency,
X = reactance, and
R = resistance.

Relative Q_{slot} and Q_{dipole} are computed for various cavity sizes V, and distances, S, respectively, for frequencies F_1, F_2, and F_3, as shown in Figure 1. In plotting these curves, it is assumed that two element antennas are mounted on the pod, that the maximum allowable space for the cavities is V cubic feet, and that the maximum allowable protrusion for the dipoles is S inches. Relative rather than absolute Qs are presented in the figure in order to avoid classified data. Figure 1 shows that the Q of the cavity-backed slot antenna is higher than that of the dipole except for frequencies near F_3. Since the potential impedance bandwidth is roughly inversely proportional to Q, the potential impedance bandwidth for a dipole is larger than that of a slot when mounted on an infinite ground plane or a pod of large diameter. Furthermore, if four, instead of two, elements are employed in the array, the bandwidth of the slot will be reduced to one-half the present value while that of the dipole will remain unchanged.

A comparison between the radiation patterns of a dipole and a circumferential slot when mounted on a pod is shown in Figure 2 at one frequency. It can be seen that the pattern for the slot possesses no advantage over that of the dipole as far as the directivity, beamwidth, and backlobe suppression are concerned.

Other advantages of the dipole approach are the availability of existing computer programs and ease in experimental tweaking of the dipole. A new computer program must be developed to handle the configuration of slot antennas on a pod, while an existing wire program used in the preceding contract can be readily employed for the dipole approach. In experimental work, it is simple and convenient to vary the design parameters of a dipole such as its spacing from the pod, its location on a pod, its wire diameter and other geometries. On the other hand, it is very costly and inconvenient to modify the design parameters of a slot after the slot and its cavity are cut and formed on a model. When it is necessary to vary slot parameters, engineers sometimes use aluminum and copper tape to obtain limited modifications. This is a questionable practice because of the leakage through the tapes and the resulting inaccuracy often associated with this crude method. The crowding of cavities inside the pod also makes it virtually impossible to place the feed circuit inside the pod in the 1/10 scale model.

The above considerations formed the basis on which the slot was eliminated and the dipole was chosen as the point design approach. This decision has been communicated to the technical monitor, who approved it and gave the go-ahead for the dipole approach.

Tradeoff analyses were explicitly called for in the Statement of Work but were not discussed in detail. In the program review on 5 October 1978, Mr. Adams, the Technical Monitor, strongly emphasized the importance of the tradeoff study. This shift of primary emphasis from the point design to tradeoff analyses requires that Georgia Tech immediately define and expand the scope of the tradeoff studies to be performed. This shift will necessarily reduce the resources available for the point design effort.

In the present progress report, a list of the tradeoff studies is compiled for review by the Air Force. It is expected that the Air Force will probably add to the list other desirable tradeoffs and eliminate some low-priority items from the list. This list has been generated on the basis of the Statement of Work which specifically requires tradeoffs of the following types: (1) effects of antenna mounting under A-10, F-15, F-16, F-111 aircraft, (2) effects of pod-mounting and side-mounting, (3) ramification of requiring both squinted and broadside operation versus requiring only the broadside operation, (4) cost performance tradeoffs of varying system parameters, and (5) effects of varying the major system parameters.

In order to define the tradeoff studies, it is necessary to clarify the "system parameters" desired in the tradeoff study. Considering the level of effort of the present program, Georgia Tech proposes to define the "system parameters" as the following major antenna parameters: (1) the antenna's protrusion outside and intrusion inside the instrument pod, (2) the weight of the antenna system, (3) the antenna gains at small depression angles (near the horizontal plane), (4) mirror image lobe suppression, (5) power handling capability, and (6) tunable and instantaneous frequency bandwidth.

A list of planned tradeoff studies, as shown in Figure 3, has been compiled under these guidelines. The anticipated output from this list of tradeoff studies is shown in Figures 4-7, which are in the form of tables and curves. It is desirable that the Air Force review this list and its accompanying figures for their priority and completeness. Additions and deletions will then be made in the list to fulfill the program objectives.

In the area of computer program development, the effort in the "body-of-revolution algorithm" has been stopped because of the shift of priorities and the decision to choose the dipole for the point design. The body-of-revolution algorithm, being necessary for the anlaysis of slot antennas mounted on a pod, is desirable but not necessary for the dipole approach. The dipole-on-pod configuration can be analyzed by the wire-grid method used in the preceding contract. The resources originally allocated to this algorithm development can be redirected to meet the expansion of the tradeoff studies to be performed.

Modification of the GTD algorithm to handle the wing effects on an antenna with arbitrary radiation characteristics has been initiated. An algorithm to produce polar Calcomp plots for radiation patterns is also under development.

During the next monthly reporting period, the planned activities will include (1) completion of the GTD algorithm for an antenna with arbitrary radiation characteristics, (2) completion of the polar Calcomp plot algorithm, (3) copper-filming of the aircraft model, (4) dipole array feed design, and (5) purchase of long-lead components and materials.

Respectfully submitted,

Johnson J. Wang
Project Director

Approved:

Fred L. Cain
Chief,
EM Effectiveness Division

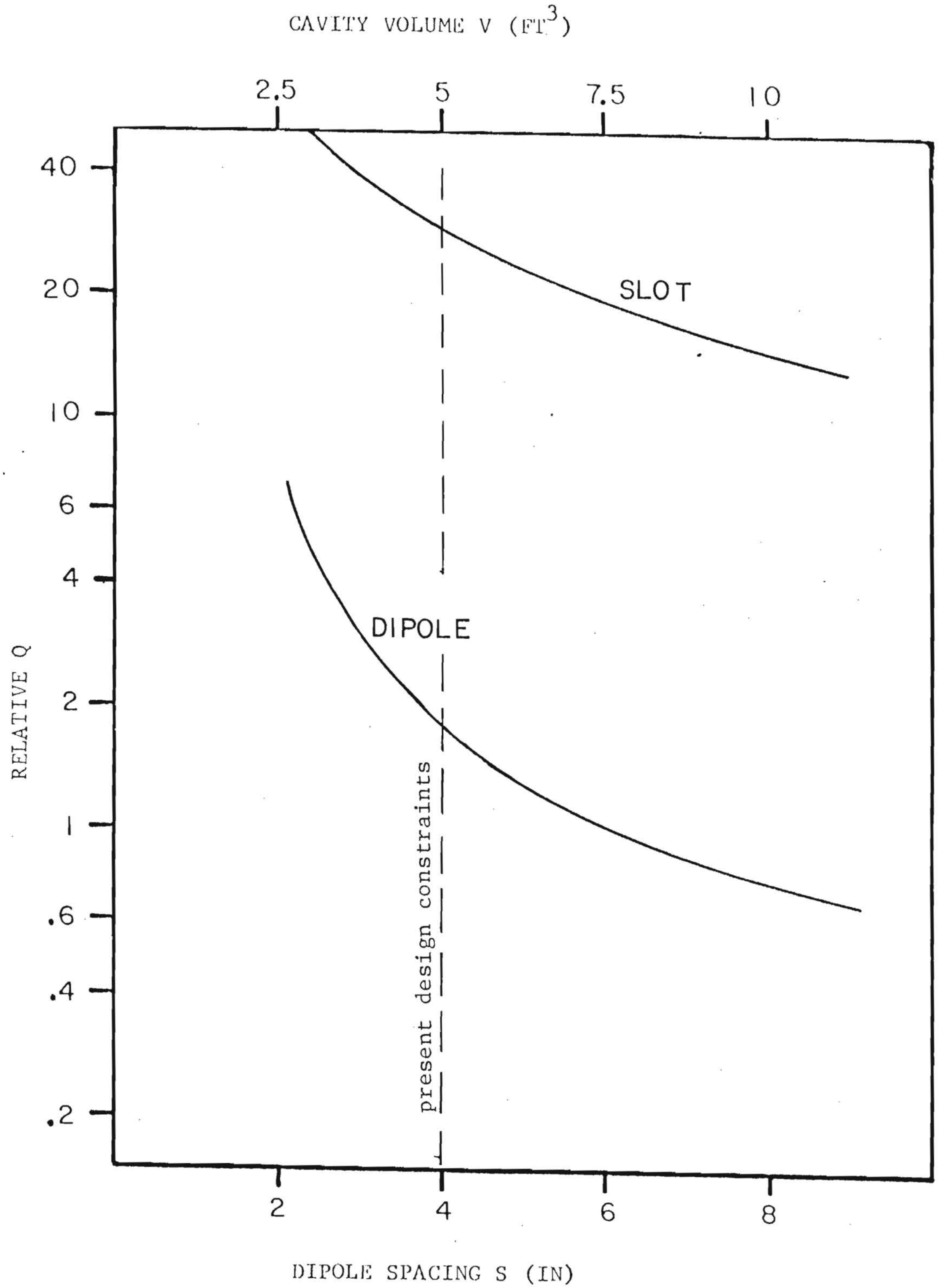


Figure 1 (a). Relative quality factor, Q, for a dipole located S inches above an infinite ground plane and a slot in an infinite ground plane backed by a cavity of volume V at frequency F1. (continued)

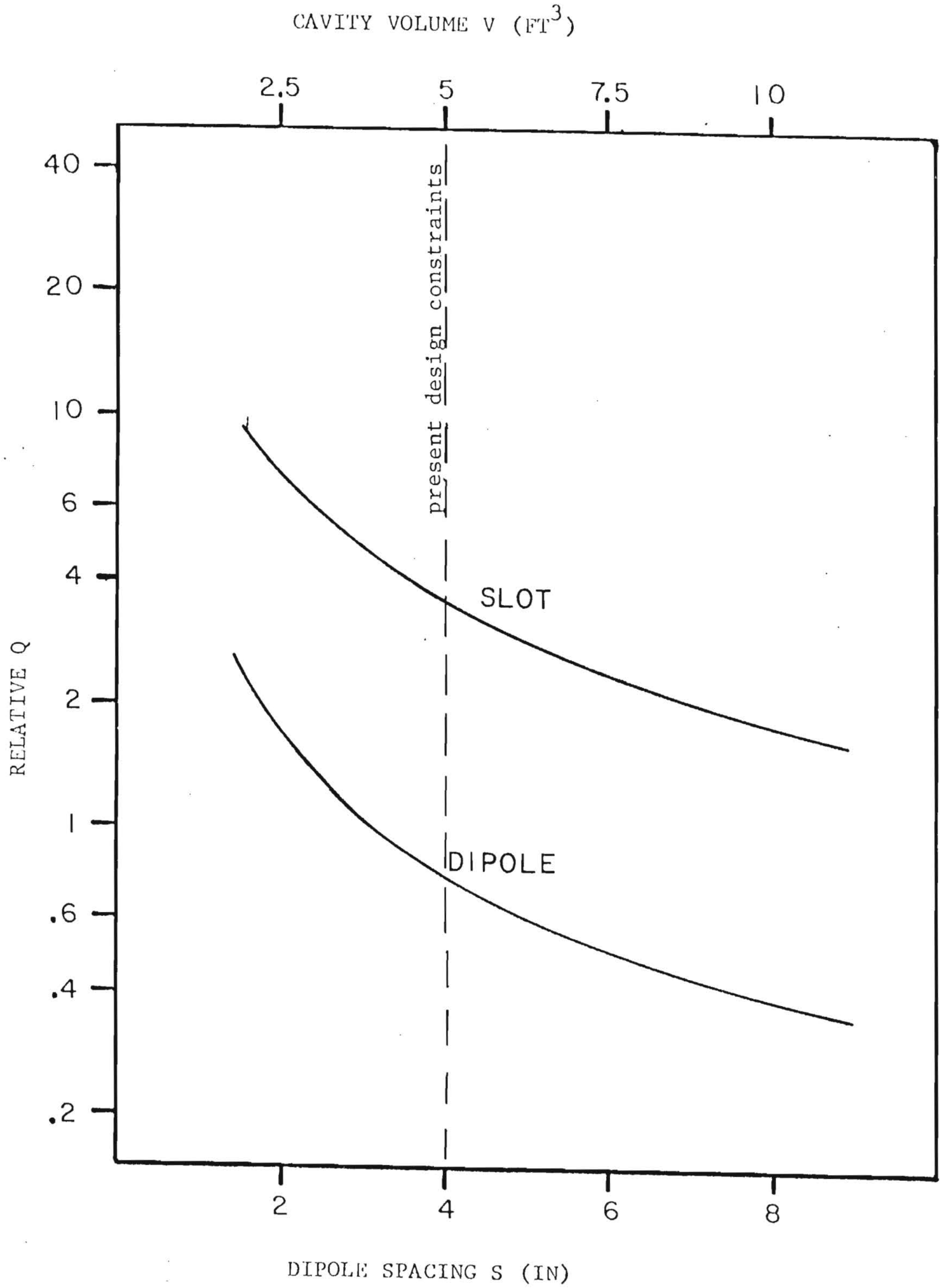


Figure 1 (b). Relative quality factor, Q, for a dipole located S inches above an infinite ground plane and a slot in an infinite ground plane backed by a cavity of volume V at frequency F2 .(continued)

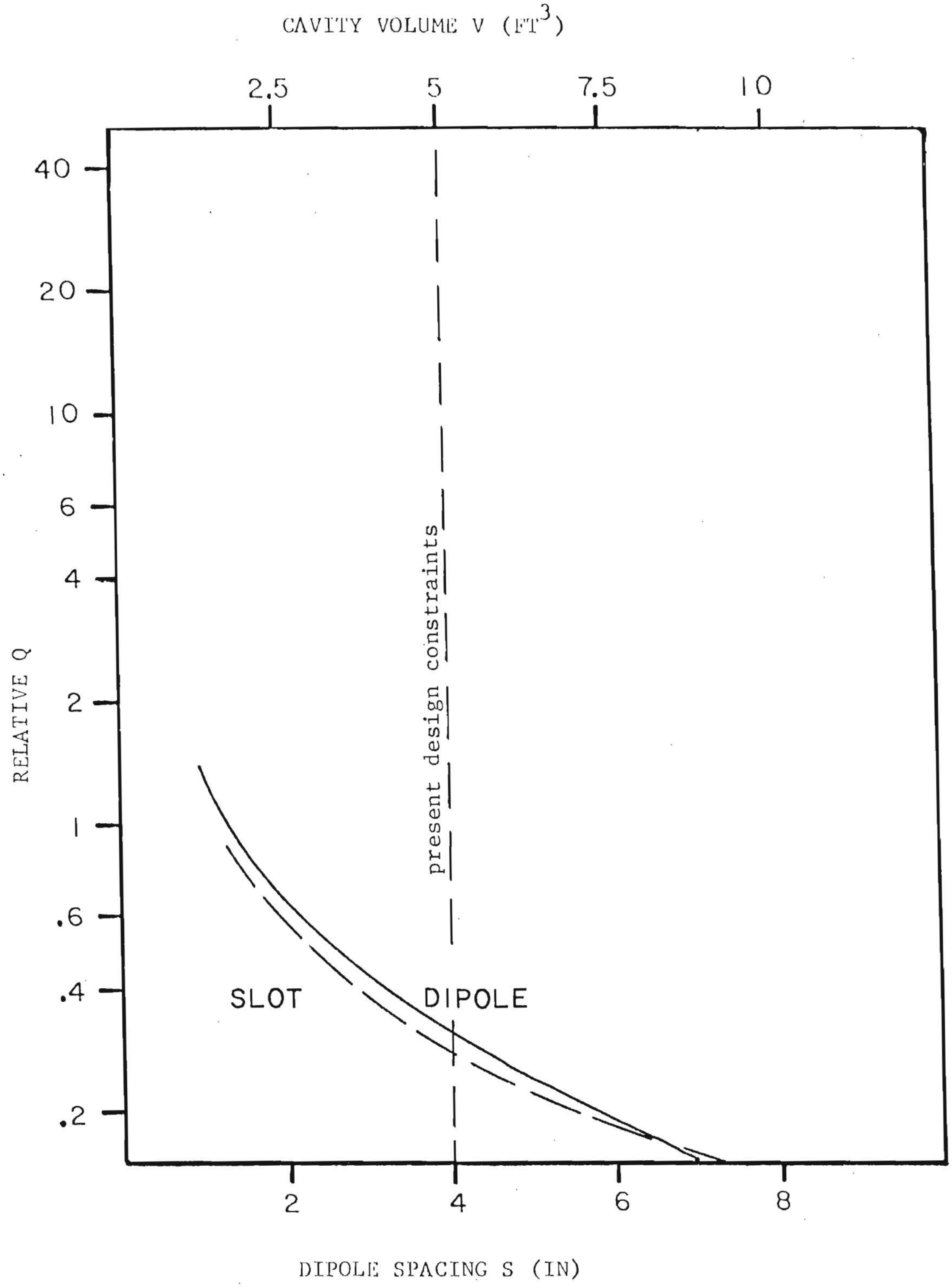


Figure 1 (c). Relative quality factor, Q, for a dipole located S inches above an infinite ground plane and a slot in an infinite ground plane backed by a cavity of volume V at frequency F3.

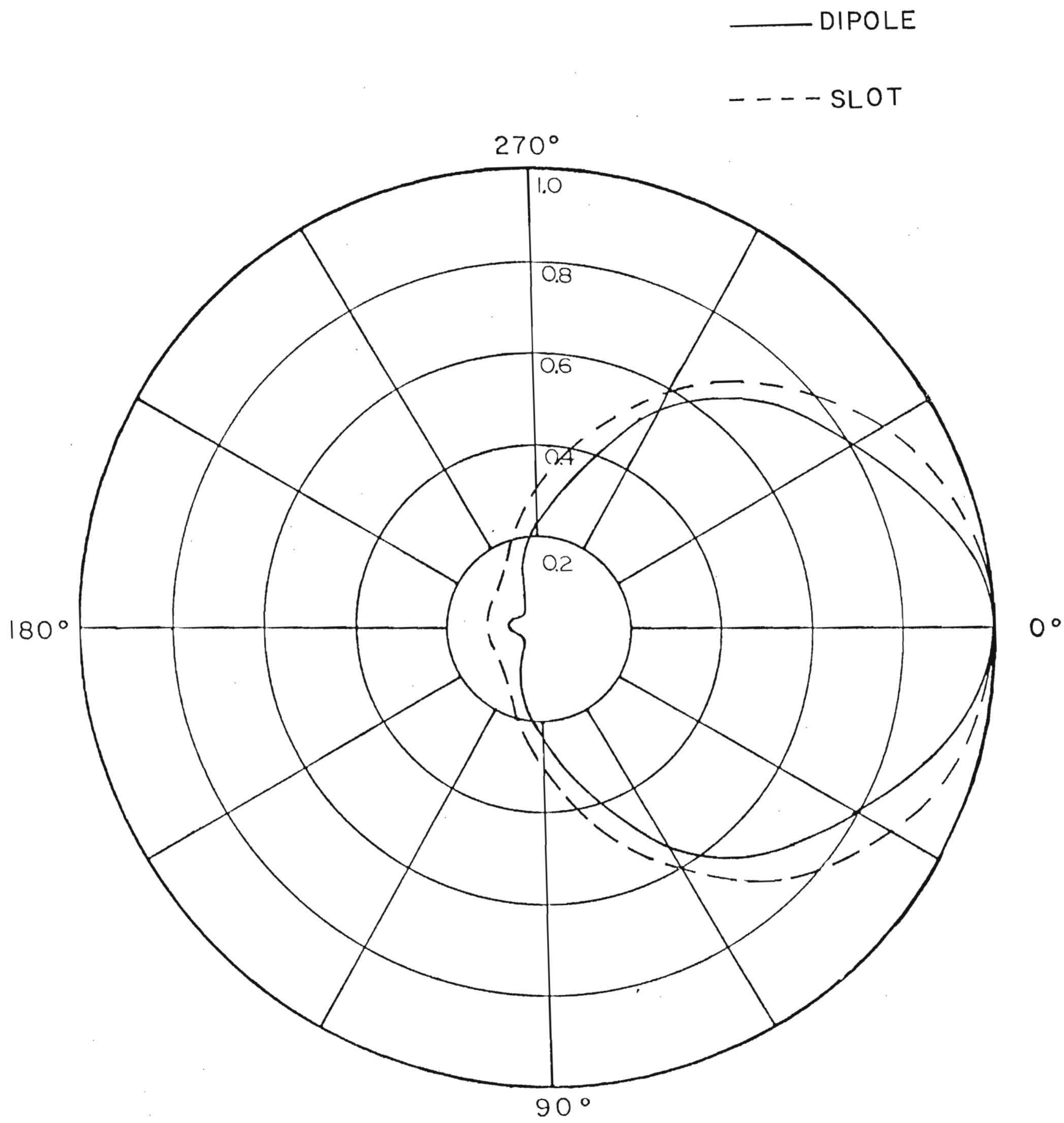


Figure 2. Roll plane patterns of a slot and a dipole element on the pod at 1.1 F_1.

A LIST OF PLANNED TRADEOFF STUDIES

1. A table which compares the effects of pod-mounting and side-mounting on the major antenna performances as shown in Figure 4 for each of the A-10, F-4, F-15, F-16, F-111, and U-2 aircraft. (A total of 6 tables.)

2. A table showing performance degradation of both side- and forward-looking antennas upon integration for each of the A-10, F-4, F-15, F-16, F-111, and U-2 aircraft as shown in Figure 5. (A total of 6 tables.)

3. Cost performance tradeoffs for various aircraft as shown in Figure 6 for pod-mounted side-looking and forward-looking antennas. (A total total of 7 figures.)

4. The effect of give-and-take between two system design parameters as shown in Figure 7. (A total of 15 figures.)

Figure 3. A list of planned tradeoff studies.

AIRCRAFT TYPE:

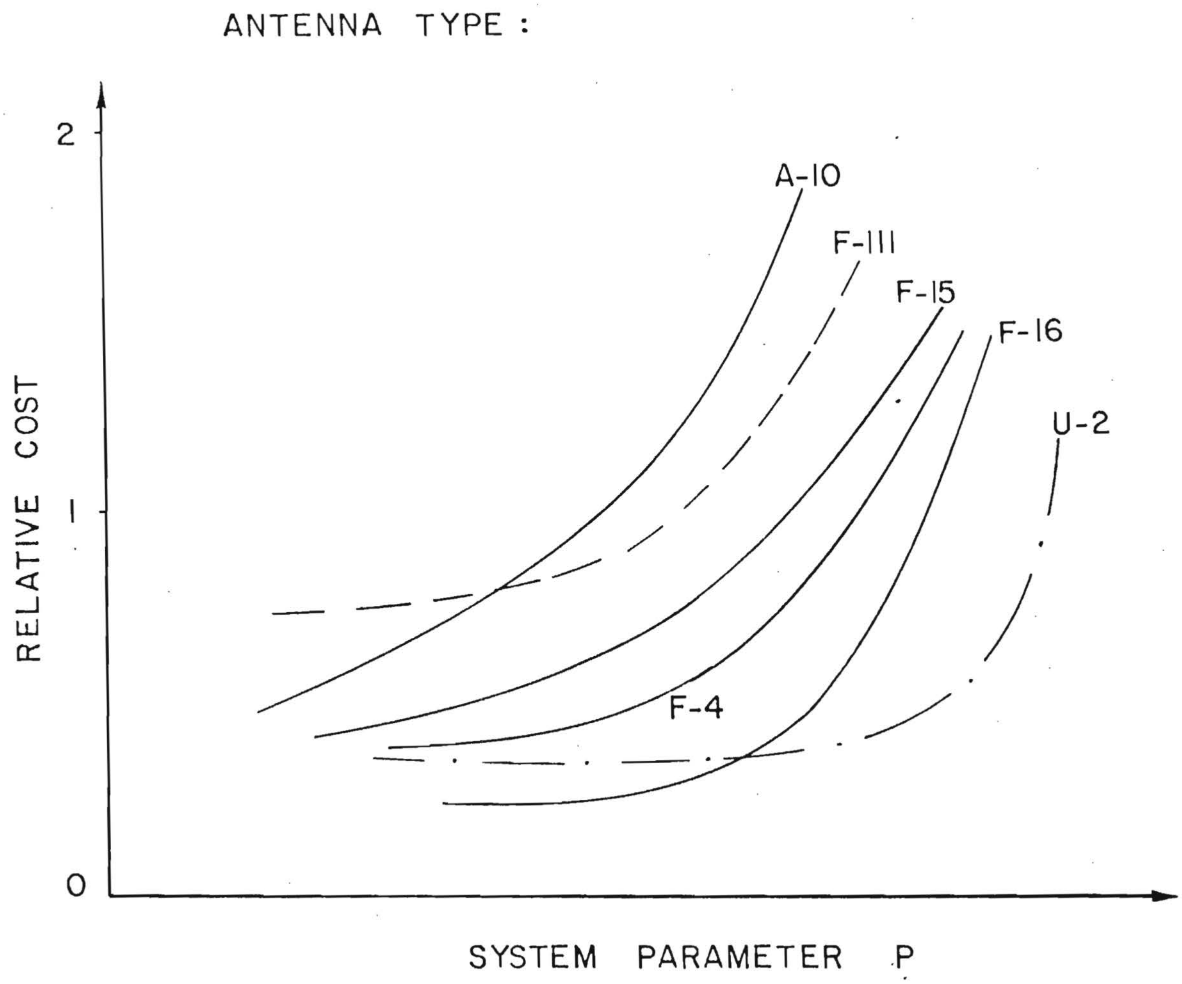
Performance Parameter	Side-Looking		Forward-Looking	
	Pod-Mounting	Fuselage Side-Mounting	Pod-Mounting	Fuselage Side-Mounting
Antenna Protrusion and Intrusion				
Antenna Weight				
Gain Near Horizontal				
Mirror Image Suppression				
Power Handling Capability				
Tunable Bandwidth				
Instantaneous Bandwidth				

Figure 4 . Tradeoff table showing antenna mounting effects.

AIRCRAFT TYPE:

System Parameters	Side-Looking Antenna		Forward-Looking Antenna	
	Before Antenna Integration	After Antenna Integration	Before Antenna Integration	After Antenna Integration
Gain Near Horizontal				
Mirror Image Suppression				
Power Handling				
Tunable Bandwidth				
Instantaneous Bandwidth				
Radiation Pattern Degradation				

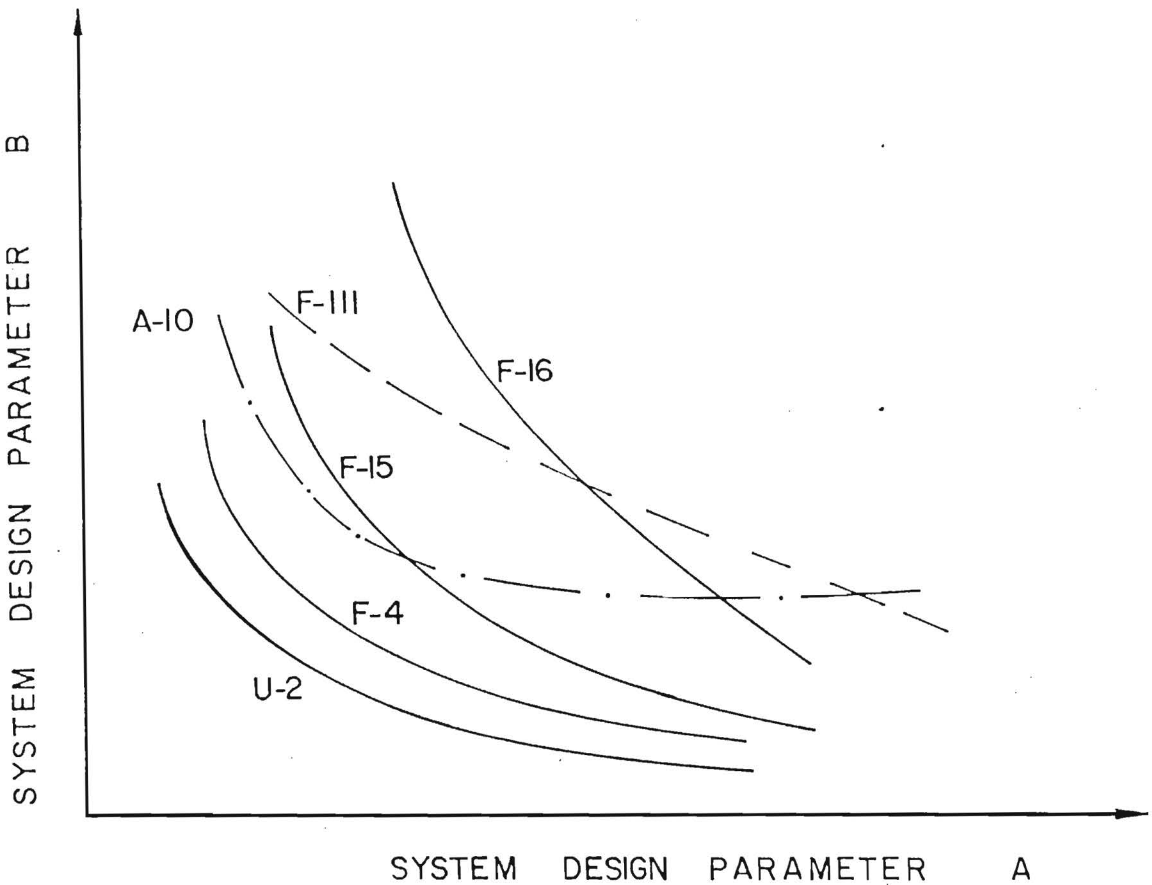
Figure 5. A tradeoff table showing antenna performance degradation upon the integration of side- and forward-looking antennas.



P denotes one of the following parameters:

1. antenna weight,
2. antenna gain near horizontal,
3. mirror image lobe suppression (dB one way),
4. peak power handling capability,
5. CW power handling capability,
6. tunable bandwidth, and
7. instantaneous bandwidth.

Figure 6. A figure for cost performance tradeoff.



System design parameters are:

1. gain near horizontal,
2. mirror image lobe suppression (dB one way),
3. peak power,
4. CW power,
5. tunable bandwidth, and
6. instantaneous bandwidth.

Figure 7. A figure showing effects on another system design parameter when one of them is varied.

A-2172

ENGINEERING EXPERIMENT STATION

GEORGIA INSTITUTE OF TECHNOLOGY • ATLANTA, GEORGIA 30332

14 August 1978

Air Force Avionics Laboratory
Air Force Systems Command
United States Air Force
Wright-Patterson Air Force Base,
Ohio 45433

Attention: Mr. C. Adams/RWM

Reference: Contract NO. F33615-78-C-1529

Subject: Cost and Performance Report No. 1
26 June 1978 through 31 July 1978

Gentlemen:

Please find enclosed the Cost and Performance Report for the indicated report period.

Respectfully submitted.

Johnson J. Wang
Project Director

Approved:

Fred L. Cain
Chief,
EM Effectiveness Division

COST AND PERFORMANCE REPORT

CONTRACT NUMBER F33615-78-C-1529 DATE 14 August 1978 CONTRACTOR Georgia Tech Research Institute

MANHOURS:	EXPENDED THIS MONTH	CUMULATIVE TO DATE	% OF TOTAL MANHOURS SPENT TO DATE	ARE REMAINING MANHOURS SUFFICIENT TO COMPLETE TASK?
	193	193	3.3	Yes

FUNDS:	EXPENDED THIS MONTH	CUMULATIVE TO DATE (Including Fee)	% OF TOTAL CONTRACT FUNDS SPENT TO DATE	ARE REMAINING FUNDS SUFFICIENT?
	$ 5,308.43	$ 5,308.43	4.29	Yes

WORK COMPLETION:	% OF WORK COMPLETED THIS MONTH	CUMULATIVE % OF WORK COMPLETED TO DATE
	4	4

A-2172

ENGINEERING EXPERIMENT STATION
GEORGIA INSTITUTE OF TECHNOLOGY • ATLANTA, GEORGIA 30332

Air Force Avionics Laboratory
Air Force Systems Command
United States Air Force
Wright-Patterson Air Force Base,
Ohio 45433

Attention: Mr. W.C. Adams/RWM

Reference: Contract NO. F33615-78-C-1529

Subject: Cost and Performance Report No. 2
1 August 1978 through 31 August 1978

Gentlemen:

Please find enclosed the Cost and Performance Report for the indicated report period.

Respectfully submitted,

Johnson J. Wang
Project Director

Approved:

Fred L. Cain
Chief,
EM Effectiveness Division

COST AND PERFORMANCE REPORT

CONTRACT NUMBER F33615-78-C-1529 DATE 14 September 1978 CONTRACTOR Georgia Tech Research Institute

MANHOURS:	EXPENDED THIS MONTH	CUMULATIVE TO DATE	% OF TOTAL MANHOURS SPENT TO DATE	ARE REMAINING MANHOURS SUFFICIENT TO COMPLETE TASK?
	383	576	9.77	yes

FUNDS:	EXPENDED THIS MONTH	CUMULATIVE TO DATE (Including Fee)	% OF TOTAL CONTRACT FUNDS SPENT TO DATE	ARE REMAINING FUNDS SUFFICIENT?
	$8,605.92	$13,914.35	11.23	yes

WORK COMPLETION:	% OF WORK COMPLETED THIS MONTH	CUMULATIVE % OF WORK COMPLETED TO DATE
	7	11

A-2172

ENGINEERING EXPERIMENT STATION
GEORGIA INSTITUTE OF TECHNOLOGY • ATLANTA, GEORGIA 30332

Air Force Avionics Laboratory
Air Force Systems Command
United States Air Force
Wright-Patterson Air Force Base,
Ohio 45433

Attention: Mr. C. Adams/RWM

Reference: Contract NO. F33615-78-C-1529

Subject: Cost and Performance Report No. 3
1 September 1978 through 30 September 1978

Gentlemen:

Please find enclosed the Cost and Performance Report for the indicated report period.

Respectfully submitted,

Johnson J. Wang
Project Director

Approved:

Fred L. Cain
Chief,
EM Effectiveness Division

COST AND PERFORMANCE REPORT

CONTRACT NUMBER F33615-78-C-1529 DATE 13 October 1978 CONTRACTOR Georgia Tech Research Institute

MANHOURS:	EXPENDED THIS MONTH	CUMULATIVE TO DATE	% OF TOTAL MANHOURS SPENT TO DATE	ARE REMAINING MANHOURS SUFFICIENT TO COMPLETE TASK?
	423	999	16.9	yes

FUNDS:	EXPENDED THIS MONTH	CUMULATIVE TO DATE (Including Fee)	% OF TOTAL CONTRACT FUNDS SPENT TO DATE	ARE REMAINING FUNDS SUFFICIENT?
	$ 8,898.85	$22,813.20	18.4	yes

WORK COMPLETION:	% OF WORK COMPLETED THIS MONTH	CUMULATIVE % OF WORK COMPLETED TO DATE
	7	18

A- 2172

ENGINEERING EXPERIMENT STATION
GEORGIA INSTITUTE OF TECHNOLOGY • ATLANTA, GEORGIA 30332

14 November 1978

Air Force Avionics Laboratory
Air Force Systems Command
United States Air Force
Wright-Patterson Air Force Base,
Ohio 45433

Attention: Mr. C. Adams

Reference: Contract NO. F33615-78-C-1529

Subject: Cost and Performance Report No. 4
1 October 1978 through 31 October 1978

Gentlemen:

Please find enclosed the Cost and Performance Report for the indicated report period.

Respectfully submitted,

Johnson J. Wang
Project Director

Approved:

Fred L. Cain
Chief,
EM Effectiveness Division

COST AND PERFORMANCE REPORT

CONTRACT NUMBER F33615-78-C-1529 DATE 13 November 1978 CONTRACTOR Georgia Tech Research Institute

MANHOURS:	EXPENDED THIS MONTH	CUMULATIVE TO DATE	% OF TOTAL MANHOURS SPENT TO DATE	ARE REMAINING MANHOURS SUFFICIENT TO COMPLETE TASK?
	538	1537	31.1	yes

FUNDS:	EXPENDED THIS MONTH	CUMULATIVE TO DATE (Including Fee)	% OF TOTAL CONTRACT FUNDS SPENT TO DATE	ARE REMAINING FUNDS SUFFICIENT?
	9693.12	32,506.32	26.2	yes

WORK COMPLETION:	% OF WORK COMPLETED THIS MONTH	CUMULATIVE % OF WORK COMPLETED TO DATE
	9	27

H-2172

ENGINEERING EXPERIMENT STATION
GEORGIA INSTITUTE OF TECHNOLOGY • ATLANTA, GEORGIA 30332

5 February 1979

Air Force Avionics Laboratory
Air Force Systems Command
United States Air Force
Wright-Patterson AFB
Ohio 45433

Attention: Mr. W. C. Adams, RWM

Reference: Contract No. F33615-78-C-1529

Title: "Multiple Frequency Antenna Study (MUFANS)"

Subject: Final Report

Gentlemen:

In accordance with contractual requirements, this letter report is submitted to meet the obligations for a Final Technical Report on the referenced contract and is submitted in accordance with U.S. Air Force instructions to summarize the present status of the project. All technical work on this project was stopped immediately upon notification of partial contract termination by the U.S. Air Force. The project status at the technical termination date is summarized in the following paragraphs.

The present status of the project can be concisely reviewed and summarized by examining the original Project Schedule and actual completion dates, as shown in Figure 1, in which the major tasks are clearly indicated. The original schedule had been submitted to and approved by the Air Force in the program kick-off meeting on 21 July 1978. Subsequently, it was also transmitted to the Air Force again in Monthly Status Report No. 1.

The work on the project was progressing ahead of schedule at the time of the termination, although Task No. 1 (the conceptual design study including the program review and final selection of antenna) was the only task fully completed. Since the progress and results of Task No. 1 have been summarized in the previous Monthly Status Report Nos. 1 through 4, no elaboration of them is needed in this report. In summary, an antenna system consisting of separate forward-looking and side-looking antennas was selected. The elements selected by Georgia Tech for the two antenna-types were (1) the dipole antenna as the element for the side-looking array and (2) a transmission line antenna or an unbalanced V dipole as the element for the forward-looking antenna.

The development of computer programs for the analysis and design of the antenna/pod/aircraft configuration (Task No. 2) has been partially completed. Specifically, Subtask 2a, the development of a computer program for the antenna/pod configuration, has been completed ahead of schedule. The original schedule for this subtask was based on a more ambitious approach -- matrix solution for an arbitrarily-shaped body of revolution. Although this approach was an ideal way to handle the problem and perhaps the necessary way to deal with slots, it was considered too risky by the technical monitor. Therefore, Georgia Tech discarded this approach in view of the risk involved and the expectation that wire antennas instead of slots would be selected in the design. The wire-grid modeling technique, used extensively and successfully in the preceding contract, was then employed to analyze the wire-antenna/pod configuration. An existing computer program for slots on an infinite cylinder was chosen to handle the slot/pod configuration. However, some input/output refinements were desirable, and these were completed before the termination date. One of these refinements was a Calcomp plot routine for the geometry of the structure and the location of sources and impedances. The plot routine facilitated the detection of input errors, which adds to the efficiency and convenience of antenna design work.

Because of a lack of existing data, only a limited assessment has been made to date regarding the accuracies of the wire-grid and infinite-cylinder computer programs. It is highly recommended that the matrix "body of revolution" method be developed if this research effort is resumed in the future. The ground work conducted in this project should enable Georgia Tech to develop this computer program with very little risk. The accuracy of this "body of revolution" approach is expected to be much greater than those of the two existing computer programs.

Task 2b, the development of a computer program to analyze the total antenna/pod/aircraft, was near completion at the time when the notice of contract termination was received. The algorithm employs GTD (Geometrical Theory of Diffraction) to compute the radiation pattern by considering only the scattering effect of the wing structure on the antenna. The prototype algorithm , which had been developed earlier at Georgia Tech, was used extensively in the conceptual design (Task 1) of the present project. However, the prototype algorithm requires the antenna pattern as input data, which must be in the form of either a mathematical expression convenient for real-time calculation or a concise file for easy access. Since the radiation pattern of the antenna/pod configuration cannot be adequately described by a mathematical expression nor be stored in a data file, further improvements of the GTD algorithm are needed. Task 2b was being conducted to address this problem by means of a technique which utilizes the current distribution on the antenna/pod structure as a medium between the antenna/pod/algorithm and on the GTD algorithm. The data file for the current distribution on the antenna/pod configuration can be computed and stored on disk in a three-dimensional array of no more than 200 elements. This current distribution file can then be used as an input data file to the GTD algorithm. However, a new subroutine must be added to the GTD algorithm to relate the input data file, consisting of current distribution, to the required input which must provide the complex vectorial field intensity at any arbitrary direction in space. All these needed improvements in the computer program were made and were being debugged at the termination of the technical effort. To complete Task 2b, further program debugging and numerical evaluation must be performed.

Some preparatory work for Task No. 3 had been initiated. These included the purchase of long-lead materials and parts. Key parts such as phase shifters and attenuators for the present broadband application are not off-the-shelf items and must be ordered several months in advance. Essentially all the orders were cancelled immediately after the partial termination notice. However, low-cost items for which the cancellation charges were near the purchase prices were not cancelled and will be handled according to contractual agreements.

In Task No. 4, a decision was made to improve the conductivity of the F4 scale-model with a thin film of copper using a mechanical leafing technique. This technique has recently been applied to another aircraft model at Georgia Tech with satisfactory results, which prompted our preference of copper-filming to the more risky plating method. Although gold-filming had been seriously considered, it was not selected because of the potential maintenance difficulties and the possible lower conductivity problem due to the glue between the gold patches. The corrosion of copper can be prevented with a thin protective plastic film.

The experimental scale-model tests for the antenna/aircraft configuration (Task 4b) have not been started. However, considerations concerning the necessary equipment and antenna range/anechoic chamber requirements for the tests have been determined and preparations for the tests were underway.

In Task No. 5, initial activity was primarily concerned with defining the tradeoff data required. This subject was extensively discussed and emphasized in the program review on 5 October 1978, the minutes of which were submitted on 17 October 1978. In Monthly Status Report No. 4, a list of planned tradeoff studies were submitted for comments and approval by the Air Force. This list consisted of four major categories, which included a total of 12 tables and 22 figures with the specified formats and parameters that were submitted to the Air Force for comments and approval.

The evaluation of impedance and reduction efficiency (Task No. 6) had not yet been started; however, considerations of the technical problems involved as well as methods for addressing them have been discussed. The existing computer programs can calculate the impedance and radiation efficiency of the wire-antenna/pod structure but will have difficulties in simulating the whole aircraft structure. The measurement of impedance and radiation efficiency will be very costly for a full-scale model. Scale-model tests will be considerably less expensive but will yield less accurate data unless the conductivity can be scaled such as in a cryogenic anechoic chamber.

The Final Report (Task No. 7), which has been reduced to the monthly letter type by the partial termination notice, is being accomplished with the present letter report.

The preceding discussion summarizes the progress to date on the referenced contract. The personnel at Georgia Tech have been pleased to have worked on this program which involves a number of interesting and challenging technical problems. As future opportunities in this or other areas arise, we would also be pleased to work with you to solve the remaining problems.

Respectfully submitted,

Johnson J. Wang
Project Director

Approved:

Fred L. Cain
Chief,
EM Effectiveness Division

1. Conceptual designs
   a. Identification of feasible antennas and conceptual antenna/aircraft designs
   b. Trade-off study of preliminary selection of antennas
   c. Program review and final selection of antenna

2. Development of computer programs
   a. Antenna/pod configuration
   b. Antenna/pod/aircraft configuration

3. Antenna system design and fabrication
   a. Antenna
   b. Feed network
   c. Pattern and frequency switches

4. Scale-model tests
   a. Copper-plating or gold-leafing of aircraft model
   b. Antenna/aircraft measurements

5. Performance trade-offs of varying system parameters

6. Evaluation of impedance and radiation efficiency

7. Final Report
   a. Final report draft
   b. Final report

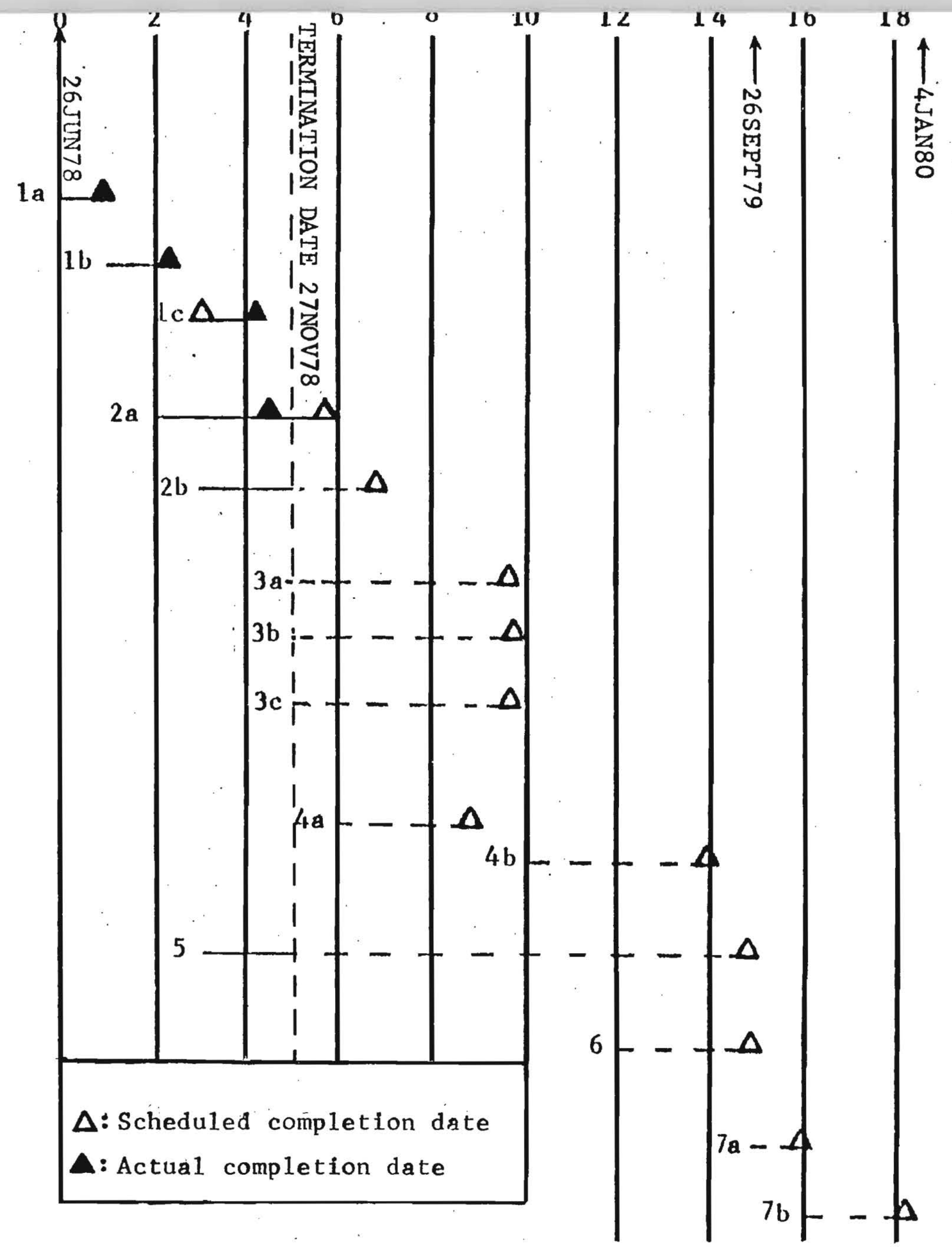


Figure 1. Project Schedule and actual completion dates